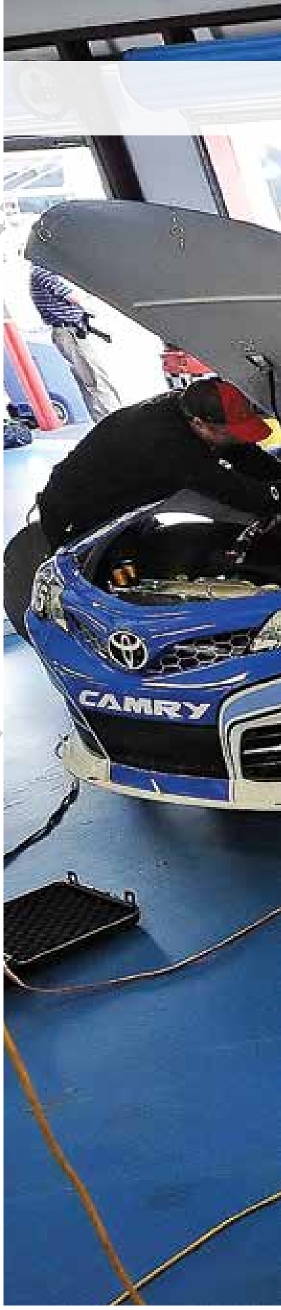
Lawrence Butcher looks into the methods and tools NASCAR teams use to offset the lack of data acquisition under race conditions



Sim City

Data logging and analysis is an intrinsic part of modern racing; from the grass roots to the upper reaches of the sport, drivers and engineers now rely on data to aid performance. NASCAR is no different, with data acquisition and vehicle simulation an indispensable tool in any team's engineering armory.

However, thanks to edicts laid down by the regulations, they are not permitted to run any form of data acquisition during race weekends (bar the small quantity now made available from the EFI system's ECU). The only feedback available to the crew chief is from the driver and the lap times. The teams are allowed to log data in testing sessions, but such sessions are few and far between – a situation that has led to a unique approach to data logging, analysis and simulation.

Feeding the sims

As Drake DeVore, NASCAR track support engineer for data logging equipment supplier MoTeC, explains, "Testing in NASCAR is now not about learning about the car, it is about validating the simulations. The testing style is unique compared to other areas of racing."

"Normally, when say a sportscar team is testing, the car will go out for a long session and you come in at various points to make changes, with those changes being based on the data or driver feedback. In NASCAR testing they test all day long, except for breaking for lunch, and they go to the track with a preset list of changes that you don't deviate from. The driver will make two or three hot laps, and when the car comes in they will make the predetermined changes; the driver will then go out and make another three hot laps, and that process continues all day. They will end up completing 20-25 runs in a day."

If an IndyCar or ALMS team undertakes a test, the data generated during a car's run is analyzed in the pits and used to determine the next set of changes to be made. At a NASCAR test this is not the case; instead, all the data engineers trackside are doing is making sure the data being gather is valid.

"They are not looking at it [the data] to determine what the car is doing, it is too hectic for that," says DeVore. "They are determining that all the sensors are working properly, that the shock pots and accelerometers are reading properly." Any loss of data gathering ability would be disastrous, as for the next two weeks the focus for a team's engineering department will be on sifting through the gathered data and using it to validate their seven-post test rigs and simulation models.

"Everybody in NASCAR programs their own simulations," DeVore points out. "Toyota has its own simulation package, RCR has its own too, and all the simulation is done in-house." Before attending a track test, a team will run its simulations and transfer the set-up to the test

Data acquisition during testing plays a pivotal role in helping teams create reliable simulations of their cars' behavior (Image: NASCAR)

car, then when they are done testing they compare the track data to the simulated data and make sure the simulated performance and actual performance match.

This leads to the peculiar situation where the simulations undertaken before a test are not necessarily geared to improving car performance, but instead simply to provide a series of base set-ups to allow a team to validate the quality of its simulation data. This means that once it comes to generating set-ups during the race season – when no data is available – teams can concentrate on improving the car's simulated performance and be confident that these improvements will translate to the track.

"Testing in NASCAR is now not about learning about the car, it is about validating the simulations"

Systems overview

There is no such thing as a 'standard' NASCAR data set-up; the systems used will vary depending on which aspects of a car's set-up a team wants to investigate. While racecars in other series may often have a standard data system fitted during their initial build, as an integral part of the vehicle's wiring, this is not the case in NASCAR. This is because the data systems and associated wiring are fitted before testing, and removed afterwards.

Regardless of the differences in sensor suites used, however, invariably a system will be based on a centralized data acquisition unit, capable of being expanded to accommodate varying numbers of inputs. "We have a standard bit of kit called the ACL 6 [Advanced Central Logger], which is a CAN [Controller Area Network] bus six-input system with 1 Gbyte of onboard logging," says DeVore. "We combine this with corner modules which we call SVIMs [Sychronized Versatile Input Modules] and there are typically four to six of these on a car, with 26 inputs a piece. This gives you in excess of 100 inputs."

Feeding the central logger will be a host of sensors (see sidebar) ▶

Equipment for data logging must be easy to fit and remove, leading to somewhat 'temporary' looking installations (Image: Lawrence Butcher)

providing data on all aspects of the car's behavior. Force measurement sensors will include, but are not limited to, shock potentiometers, accelerometers, load cells on the sway bar drop links, damper attachment eye load cells and load cells on the spring perches. The steering system will also be instrumented with load cells on each steering arm. Some teams even use a full wheel force measurement system, the operation of which is again described in the sidebar, to generate huge amounts of data on the loadings through each individual wheel.

In addition to load-based sensors, teams will also use sensors to look at tire temperatures and ride heights. Typically cars will run with two height sensors in the rear and two in the front corners, and many teams will also put two or three sensors on the front splitter so that its movement can be tracked. Splitter height – or, more specifically, control of the splitter height – is vital to the effectiveness of a stockcar's overall aero performance, and is thus of considerable interest to a team's development engineers.

As well as these basic types, DeVore notes that any team that takes data acquisition seriously will also be using slip angle sensors. These tend to be optical tracking-based units, and by using two sensors it is possible to calculate factors such as the slip angle at the front or rear of the vehicle, the location of the yaw axis and the yaw rate of the vehicle.

Controlling all these sensors is a challenge, and the integration of ever more sensors is an area of constant research among teams and suppliers. "A lot of the stuff that is being done now is moving to CAN-based sensors, which allows for many more signals to be processed," says DeVore. "Some of the more interesting things people are doing involves looking at the tire temperatures and profiling the temperatures across the tire."

Tire temperatures are a vital factor in determining a car's performance, with tire wear – and, more important, monitoring that wear – being a key factor contributing to raceday performance. To help teams gain a greater understanding of their tires a number of companies are making infrared sensors that actually bend around the tire to look at the sidewall temperatures. This allows engineers to gain a far better picture of the overall temperature state of a tire than is possible with a reading taken from a single point on the tire carcass. "We have created channels in the logging software to allow teams to view this data as a temperature profile across the tire, which they find really useful," says DeVore.

"The chassis of a Cup or Nationwide car is – by modern racecar standards – very compliant"

Being made of steel tube, the chassis of a Cup or Nationwide car is, by modern racecar standards, very compliant, and chassis flex plays a major role in a car's handling behavior. Understanding how a particular car's chassis behaves under load, and the interactions between the various flexing moments in the chassis, is important to ensure set-up changes give consistent results. To provide the data

SENSING TECHNOLOGY

A data acquisition system is useless without sensors to measure the parameters engineers want to study. The array of instrumentation available to engineers for use during testing is constantly expanding, and sensor manufacturers are constantly improving the accuracy and reliability of their products while at the same time reducing their size and increasing their functionality.

Tire temperature and pressure

Infra Red temperature sensors are vital for gaining an understanding of tire and brake temperatures (Image: Texys)

In the past, tire temperatures could only be measured when a car was in the pit lane, using a pressure gauge and a thermal probe. Miniaturization of infrared-sensing technology, however, has allowed tire temperature measuring equipment to be incorporated into a car's sensor package, providing real-time information on tire condition.

There are three key methods for measuring tire temperature – external infrared sensors mounted close to the tire, infrared cameras, and measuring devices incorporated into the wheel to measure carcass temperature. The most basic temperature measuring systems consist of a 'single-channel' infrared sensor that is pointed at a narrow strip of the tire's surface, but that doesn't provide an overall picture of tire temperature. More advanced systems now overcome this by using multi-channel infrared sensors that can measure multiple sections of tire simultaneously, all packaged in a unit weighing about 15 g. The latest versions have further functionality thanks to a flexible mounting. This allows them to be effectively 'wrapped around' the tire, to measure both tread and sidewall temperatures.

Infrared sensors are also used to study other temperature-sensitive areas of the car. For example, on short tracks and road courses the under-braked nature of a Cup car makes brake temperatures an area of particular interest to engineers.

Wireless tire-pressure monitoring systems are now the norm in NASCAR, and consist of a sensor unit mounted on the tire valve stem and a receiver unit connected to the main data logging loom. As with tire temperatures, tire pressures would in the past have been checked in the pit lane, but these readings varied considerably from on-track pressures as the tires cooled coming into the pits; now though, pressures can be logged dynamically at any point in a lap. The latest systems also combine pressure and temperature measurement in a single unit using a shared ECU, providing an integrated and therefore more compact solution.

Suspension movement

Some of the most important sensors in a data acquisition system, in terms of performance optimization, are those that measure suspension movement. Invariably these will be potentiometers that provide a signal representing suspension movement, and the particular suspension system being used on a car will dictate whether a rotary or linear potentiometer is used. Linear potentiometers mounted directly on the dampers are the most common method for measuring suspension movement; however, advances in contactless position sensors are also making them attractive for suspension logging. In the past, such sensors needed to assess the impact of movement in the chassis and other components, teams have gradually added more and more strain gauges to their data set-ups in order to measure the tolerances present.

DeVore highlights the steering system as an example of the type of information engineers are trying to glean during testing. "Typically, in something like an ALMS car, you would put one linear potentiometer in the steering system, or even just measure steering wheel position with a rotary pot," he says. "In NASCAR, teams now want to see things like left-wheel versus right-wheel angles, and compare these to the steering box position. In addition to measuring the movement, they also want to know the forces acting on the steering arms. You have your steering rods with ball joints, the rod and the joint have a different amount of deflection, and are made of different materials which have a different bending moment.

"All of these contribute to the car's behavior, and when you only put a single steering angle sensor on the car you are not considering these factors. The teams are taking it to a whole new level compared to what they were doing in the past."

Beyond the obvious 'traditional' data logging methods, new techniques – for example the video logging of movement in components such as the suspension arm – are also starting to grow in popularity. In the case of video recording, while data will show movement, it is sometimes easier to identify issues visually, in order to highlight areas that may need to be instrumented for further investigation. The reduced cost and size of high-definition compact camera systems such as the GoPro series now makes it practical to package them in inaccessible areas such as under fenders.

"Teams will mount a number of cameras around a car and get a visual of what the data is showing them," explains DeVore. To make this data useful, many loggers now have the ability to integrate digital video into a dataset and make it time-synchronous with the data, allowing engineers to see what the car is doing at the same time as viewing the data. Another area where video has been found to be useful is in assessing the impact of drafting on car behavior. Knowing the location of a car in relation to other vehicles on the track is critical from an aero analysis viewpoint.

DeVore explains that this is a very helpful development for data analysis engineers. "You can look at the data gained from a group test, but if you have no idea how close you are to the other cars on the track, or where the other cars are located, you cannot be sure how their wakes will be offsetting your data," he says.

Pushing the boundaries

"Out of all of our projects, these guys in NASCAR have pushed our data kit more than any other group of racers," DeVore says. "We have had some really unique requests in terms of what they want to do, both in terms of data collection and analysis, which are really brilliant and unique ways of looking at things and studying the cars. It's led to a great relationship because it is constantly pushing us to improve our equipment."

Data acquisition has only been in widespread use among stockcar teams for the past 15 years, and over this period DeVore has seen a sharp increase in the level of data use. "I think that in the last five

> "Teams are devising systems to allow them to log anything up to 500-600 Can channels at the same time"

to ten years it has become something that the teams are completely dependent on, rather than working out their set-ups from experience and historical data," he says. "The increased dependence on simulation is, by its very nature, increasing the dependence on data acquisition to feed the simulators. Teams keep pushing it further and further, realizing that adding a sensor here and there can give them information on a piece of the car that they may not have even paid attention to in the past. It has got to the point where we know what the car does from a basic standpoint, and we now need to start looking at the individual components to get the simulations to work properly."

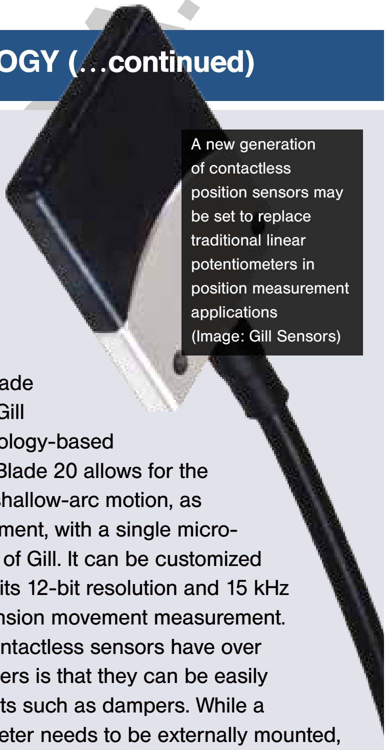
Clearly the restrictions placed by NASCAR on track testing time are a major factor in the rapid advancement of data system capability. Aside from making as many runs as possible in a day, the only way teams can gather more data in a day's running is to increase the number of channels they are logging. This has led to some teams developing new ways to harvest sensor data. Beyond the 100-plus channels available in off-the-shelf loggers such as that from MoTeC, teams are devising systems to allow them to log anything up to 500-600 CAN channels. However, they are understandably tight-lipped about the methods used to achieve such high levels of data acquisition.

"A lot of this increase has been made possible thanks to advances in CAN-based sensors," DeVore explains. "I have seen teams running 12 or even 24 tire temperature sensors per corner and transmitting the signals through CAN. Then, when you get into the wheel force systems the teams are using, they are generating huge numbers of data channels." DeVore adds that the intention behind the gathering of this vast volume of data is to try to offset the impact of the limit on track testing time. "If you put enough sensors on the car, so you can measure absolutely everything, it means that later on when you are studying all the data and running the simulations, if something comes up that is not directly measured you have enough information from other areas to calculate it," he says.

The depth of data insight that teams are now demanding, and the high level of development within their simulation packages, has forced data equipment suppliers to raise their game. One area of progress that highlights the level of precision at which these simulations are operating relates to potential variances in simulated and actual performance due to processing delays within the logging units.

As DeVore explains, "If you imagine a car on a seven-post rig at a ▶

SENSING TECHNOLOGY (...continued)



A new generation of contactless position sensors may be set to replace traditional linear potentiometers in position measurement applications (Image: Gill Sensors)

lacked the resolution or response rate to make them an effective method for suspension measurement, but new designs have gone some way to overcome those disadvantages.

One such sensor is the Blade 20, produced by UK-based Gill Sensors, an induction technology-based linear position sensor. "The Blade 20 allows for the measurement of linear and shallow-arc motion, as well as long-stroke measurement, with a single micro-sensor," explains Mike Rees of Gill. It can be customized for various roles which, with its 12-bit resolution and 15 kHz update rates, include suspension movement measurement.

The big advantage that contactless sensors have over traditional linear potentiometers is that they can be easily incorporated into components such as dampers. While a mechanical linear potentiometer needs to be externally mounted, contactless sensors use induction technology to detect the position of a metallic target (referred to as the 'activator') which is mounted to or machined into the moving part of the component. In the case of a damper, the activator can be incorporated into the damper shaft. Beyond convenient packaging, contactless sensors do not have any moving parts to wear out, making them ideal for use in the harsh environments found in a stockcar.

Wheel force measurement

The most common system for wheel force measurement comes in the form of a complete replacement wheel, which has load cells incorporated to measure deflection in every direction, with measurements being taken from each quadrant of the wheel. This yields force traces in the x, y and z axes from each wheel, and these systems also incorporate accelerometers to measure velocity, multiple TPMs (tire pressure monitors) and internal temperature sensors. The result is more than 30 data channels per wheel.

These systems are normally used in OEM product development, and are not cheap; however, NASCAR teams have found the data they provide invaluable. Drake DeVore, a NASCAR track support engineer for MoTec, explains that the data produced by wheel force measurement systems is particularly relevant in stockcar racing applications. "They are really unique pieces, and the data they generate is really fun to look at; with all the movement in a stockcar's steel wheel there is a lot going on [from a kinematics perspective]. Lateral loading and lateral aero is a big thing for these teams, and this kit allows them to look at exactly what each wheel is doing."

Strain gauges and load cells

A large number of sensors, normally strain gauges, are used to assess the loads exerted on individual components in the suspension and chassis to provide invaluable data for inputting into full-body vehicle simulations.

A strain gauge is an electrical resistor made from a foil section bonded to a dielectric backing. When the gauge is stretched or compressed, its resistance varies, and this change can be correlated to the amount of force on the material by converting the change into a voltage using a device called a Wheatstone bridge. ▶

simulated 200 mph, the delay in the sensor signals reaching the logger from the front-left and front-right corners is significant enough to affect the output of the simulation." This is because a processor, by nature, can do only one thing at a time – albeit very quickly – and teams were noticing a very subtle offset in the time it was taking the logger processor to deal with the individual sensor reading. This means that some very clever data processing must be employed to prevent this phenomenon skewing the simulation result.

"What we have done is design the module to allow the central logger to synchronize the samples coming in from all of the sensors," DeVore says. "So although the samples come into the processor in sequence, they were all taken at the same time, and we have an algorithm that ensures they are outputted from the logger synchronously. That means we can have 118 channels when using eight SVIMs, all of which are outputting at exactly the same time. The result is that in the simulation you do not experience processor phase delay from the sequence of the processor doing one task at a time."

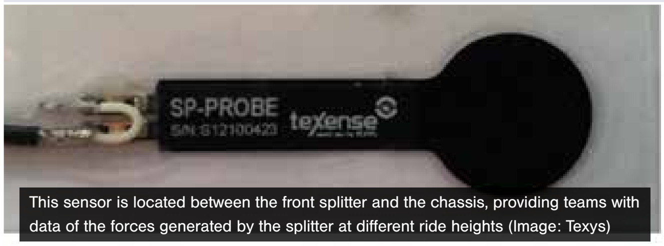
Conclusion

It would be fair to say that the level at which the top NASCAR teams are working with data analysis is probably surpassed only by teams in Formula One and possibly some works-backed sportscar outfits. This reliance on data – or rather on the simulations made possible by possessing in-depth data on car behavior – is directly related to the conditions under which teams in the NASCAR Sprint Cup have to race.

If cars were allowed to be outfitted with data systems during race weekends, simulation packages would not be made redundant, but could be verified on a week-by-week basis, using data gathered during racing. That would then reduce the volume of data teams would feel obliged to collect pre-season, which is currently needed to ensure that their simulated in-season set-ups will perform on the track. So unless there is a sudden shift in regulations that allows cars to be data-equipped permanently, the top teams will inevitably continue to find new ways of harvesting ever-increasing amounts of data from their limited track testing times. As long as there is scope to improve the accuracy of simulation packages, there is going to be a drive to find more data to feed them. ■

All of the data gathered during track sessions will be fed into a teams simulation and rig testing programs (Image: Lawrence Butcher)

SENSING TECHNOLOGY (…continued)



This sensor is located between the front splitter and the chassis, providing teams with data of the forces generated by the splitter at different ride heights (Image: Texys)

Applying a voltage to the bridge creates an output signal, and it is then possible to create an algorithm in the data acquisition software to convert this output into a unit of force.

The advantage of strain gauges is that they can be incorporated into a wide variety of components made from a range of materials, for example a suspension wishbone .

Dampers, bump stops and spring perches will also be outfitted with load cells to measure the individual bump forces experienced by each damper. These load cells consist of a Wheatstone bridge in a housing that can be deformed under compression, with the resulting output representing the force applied to the cell.

Ride height

Dynamic ride height measurement is important for assessing overall levels of downforce on a car, and to ensure that the floor is being kept at the optimum height from the ground. This is normally achieved using a laser ride-height measurement system, which consists of several laser units positioned around the car. These allow for accurate recording of ride height, although teams have to be careful in their placement as the sensor lenses can easily be obscured by debris. Teams will also place a number of height sensors along the splitter in order to track its distance from the ground.

Aerodynamic loads

The sensors used for this work fall into two categories, those that measure air pressure and those that measure aerodynamic loads on surfaces. As mentioned above, the suspension in a car features an array of strain gauges and dedicated load cells, part of whose role is to measure the loads created by downforce. However, they can only provide data on the distribution of forces front to rear and corner to corner, so more sensors are needed to ascertain loads and pressures at particular points on the car.

Supplier Texys has also introduced a new 'splitter measurement unit' (pictured) to help teams study the loads acting on the front splitter. The primary function of the sensor is to evaluate how often and to what degree the splitter touches the track.While it inevitable that the splitter will contact the track surface, teams want to minimise the frequency of such events, so the sensor allows them to asses the effect of varying ride heights on splitter/track contact. In a secondary role, the sensor can also provide a good gauge of aerodynamic load on the splitter as the car runs along the straights.

Pressure measurement

The most common method for collecting pressure data is through the use of pitot tubes, often arranged in arrays to analyze flow in a specific area. The tubes are available with built-in processors to provide individual pressure readings, usually to gauge airspeed, and can often be seen on cars in test configuration mounted high up above the airbox in clean airflow. The processor built into the base of the pitot compares the dynamic and static pressures to provide an accurate airspeed reading.